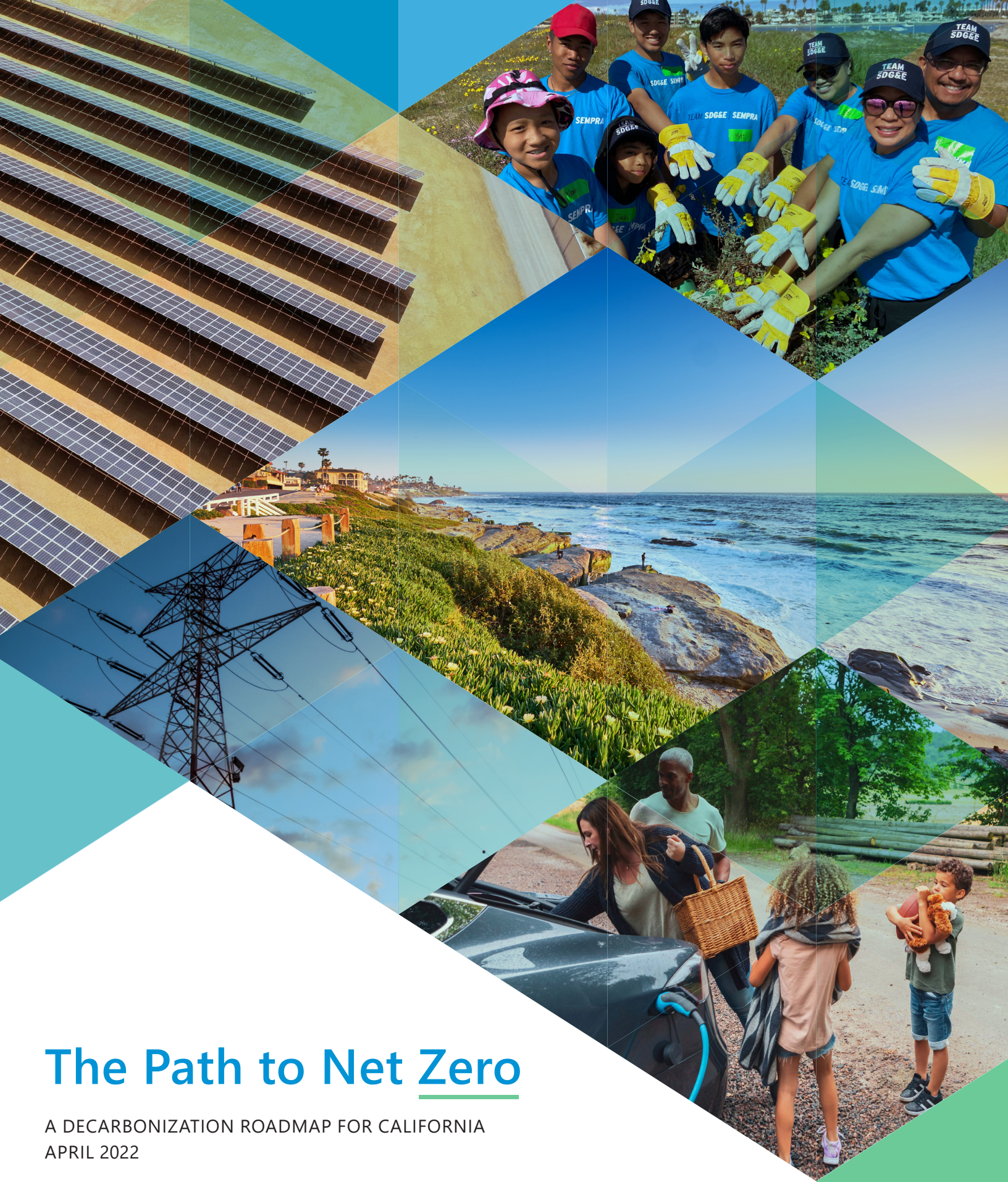

The Path to Net Zero

A DECARBONIZATION ROADMAP FOR CALIFORNIA

APRIL 2022

SDGE™ BCG BLACK & VEATCH

About the contributors

SDG&E®

SDG&E is an innovative San Diego-based energy company that provides clean, safe and reliable energy to better the lives of the people it serves in San Diego and southern Orange counties. The company is committed to creating a sustainable future by providing its electricity from renewable sources; modernizing natural gas pipelines; accelerating the adoption of electric vehicles; supporting numerous nonprofit partners; and, investing in innovative technologies to ensure the reliable operation of the region's infrastructure for generations to come. SDG&E is a subsidiary of Sempra (NYSE: SRE). For more information, visit SDGEnews.com or connect with SDG&E on Twitter (@SDGE), Instagram (@SDGE) and Facebook (https://www.facebook.com/SanDiegoGasandElectric).

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David G. Victor

David Victor is a professor of innovation and public policy at the School of Global Policy and Strategy at University of California (UC) San Diego. He co-directs the campus-wide Deep Decarbonization Initiative, an effort to understand how quickly the world can eliminate emissions of warming gases. He is an adjunct professor in Climate, Atmospheric Science & Physical Oceanography at the Scripps Institution of Oceanography and a professor (by courtesy) in Mechanical and Aerospace Engineering. Prior to joining the faculty at UC San Diego, Victor was a professor at Stanford Law School where he taught energy and environmental law. He has been heavily involved in many different climate- and energy-policy initiatives, including as convening lead author for the Intergovernmental Panel on Climate Change (IPCC), a United Nations-sanctioned international body with 195 country members that won the Nobel Peace Prize in 2007. His Ph.D. is from the Massachusetts Institute of Technology and A.B. from Harvard University.

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1. Executive summary

California has set ambitious climate goals by adopting into law Senate Bill (SB) 100, which requires 100% zero-carbon energy by 2045, and is committed to achieving a just and equitable energy transition on its path to carbon neutrality (Net Zero).[1] The state must undertake a significant transformation and decarbonize at 4.5 times the pace it has over the past decade to achieve carbon neutrality by 2045 and help mitigate the negative impacts of climate change. California already serves as a global sustainability leader. Given its decarbonization experience, innovative spirit and commitment to equity, its carbon neutrality goal presents California with an opportunity to demonstrate how a major economy can decarbonize in a reliable, affordable and equitable way.

The Path to Net Zero: A Decarbonization Roadmap for California (*Roadmap*) examines the implications of this transition for the state and the region San Diego Gas & Electric (SDG&E) serves. It also includes SDG&E's recommendation for California to achieve carbon neutrality, and is the first publicly available analysis to use the industry standard for electric reliability and industry modeling software in modeling how to decarbonize California by 2045.

As many other studies have highlighted, electricity is expected to play a central role in decarbonization. But there are also critical roles for other forms of clean energy, including renewable natural gas and hydrogen. While the *Roadmap* recognizes uncertainties that require new, flexible approaches to technology and policy, it also highlights areas where the priorities are clear. These include the need to expand electrification and supplies of solar and wind power, invest in a diverse set of electric generation resources that will help ensure the electric grid is reliable and lastly, to provide much larger volumes of clean fuels.

Electrification is central to decarbonizing the transportation and building sectors under the *Roadmap*. It is estimated that electric generation capacity will need to increase to 356 gigawatts (GW) by 2045 in California to meet this increasing demand for clean electricity, approximately four times the capacity that existed in 2020. The *Roadmap* foresees in-state solar and wind generation providing the bulk of this capacity.

Wind and solar are excellent resources for providing low-cost clean energy, but to help ensure reliability, the California electric system must also develop more flexible resources, such as energy storage and clean dispatchable generation.[2] This is especially important as the need for clean, reliable electricity increases from transportation and building electrification. We believe this will require installing 40 GW of new battery storage as well as 20 GW of dispatchable generation from 100% clean hydrogen generation by 2045.[3] Moreover, in addition to existing natural gas generation, we believe that 4 GW of electricity from natural gas with carbon capture and sequestration (CCS) will be needed to support reliability as the electric sector decarbonizes. Combined, these flexible resources can provide clean electricity when the sun is not shining and the wind is not blowing and ensure that high electricity demand during the summer months can be reliably met.

Having clean dispatchable resources that can provide carbon-free electricity when needed will be critical to help ensure a clean, reliable electric supply for a decarbonized California. Developing the necessary technology and infrastructure to enable clean dispatchable resources will be a tremendous undertaking. For example, the California electric system currently has no electric generation from 100% clean hydrogen generation.

[1] SB 100 requires that 100% of retail sales of electricity in California be served by eligible renewable energy resources and zero-carbon resources by 2045.
[2] Clean dispatchable generation refers to resources that do not produce greenhouse gas (GHG) emissions and are available any time electricity is needed, in contrast to weather-dependent wind and solar generation. These attributes are necessary to help ensure a clean and reliable electric supply, and SDG&E recommends an inclusive approach as clean dispatchable technologies continue to develop.
[3] 100% clean hydrogen generation is a type of clean dispatchable resource that burns "green" hydrogen fuel produced using renewable electricity.

FIGURE 1
The Path to Net Zero: Key Results

State of California

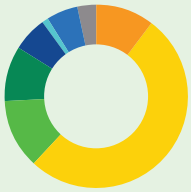
***Electrification** of transportation and buildings **is core** to the Roadmap*

96%
Projected increase in **ELECTRIC CONSUMPTION** for California between 2020 and 2045

60%
Projected increase in **NET PEAK DEMAND** for California between 2020 and 2045

*We believe a **diverse set of resources** is needed to reliably meet increased demand for electricity*

85 GW
capacity in California in 2020



356 GW
capacity in California in 2045

Natural Gas · Solar · Storage[1] · Imports · Wind · CCS[2] · Hydrogen · Other[3]

*Clean fuels, like **clean hydrogen**, can enhance the reliability of electric supply and more broadly complement electrification*

Demand for **6.5 million metric tons** of clean hydrogen across the California economy in 2045

6.5 MMT

~80% of which will be used to enhance the reliability of **electric supply**[4]

*The Roadmap meets the **state's decarbonization goals** in 2030 and 2045*

>40%
California economywide emissions reduction by **2030** vs. 1990 levels

Net Zero
Emissions achieved for California economywide by **2045**

SDG&E Service Area

***Charging infrastructure** will help enable transportation electrification*

900K
ELECTRIC VEHICLES
projected in SDG&E service area in 2030

3,230K
ELECTRIC VEHICLES
projected in SDG&E service area in 2045

180K
EV CHARGERS
projected in SDG&E service area in 2030

640K
EV CHARGERS
projected in SDG&E service area in 2045

***Electricity usage** and **demand** is expected to increase*

~100%
Projected increase in **ELECTRIC CONSUMPTION** for SDG&E service area between 2020 and 2045

~85%
Projected increase in **NET PEAK DEMAND** for SDG&E service area between 2020 and 2045

*We believe a **mix of resources** will be needed to maintain electric system reliability in SDG&E service area*

1,500 MW
2030 battery storage

2,500 MW
2045 battery storage

4 GW
2045 clean hydrogen generation

[1] Includes both battery energy storage and pumped hydroelectric storage.
[2] Natural gas generation with CCS. Includes new builds and retrofits.
[3] Other includes oil, coal, geothermal, biomass, hydroelectric, and nuclear.
[4] The remaining portion is used for pipeline blending of hydrogen and fuel cell vehicles.

As electricity consumption increases, additional electric infrastructure will be necessary for California to support decarbonization. This infrastructure will support reliability and allow California to access an estimated 34 GW of imported renewable power by 2045, which should enable the geographic diversification of renewable power and minimize the impact of localized weather events.

Resource diversity is essential to reliable, resilient and affordable decarbonization. The *Roadmap* calls for critical roles across the economy not only for clean electricity but also for clean fuels. In addition to supporting electric system reliability, clean fuels make it possible to decarbonize emissions from sources that cannot be easily electrified, such as heavy-duty trucks and many industrial processes. The *Roadmap* also requires the use of carbon removal technologies so that the GHG emissions that remain in 2045 and beyond can be removed and the goal of Net Zero achieved.

This *Roadmap* aims to provide what we believe is a reasonable and appropriate starting point for implementation and prioritization based on current knowledge, feasibility and market conditions. But the challenges, technologies and solutions associated with decarbonization are constantly evolving. The *Roadmap* will therefore need to be revisited as uncertainties are narrowed. For example, there are still unknowns about consumers' future adoption rate of electric vehicles (EV) and all-electric household appliances, as well as how the associated increase in electricity usage will impact the electric system. There are also uncertainties about the cost of decarbonization technologies. By pursuing multiple technological options for decarbonization, the *Roadmap*'s diversified approach should provide California with the necessary flexibility to adapt its path to carbon neutrality. Done right, we believe the California clean energy system can be affordable to consumers. Indeed, our modeling projects that economywide decarbonization spending as a percent of California gross domestic product (GDP) decreases over time.

Implementing the *Roadmap* will require regulatory and political support focused on four key considerations:

1. **Maintaining affordability and enhancing equity.** Policymakers and regulators will need to manage cost and equity impacts by changing how electricity and gas are priced, particularly for average and lower-income households who carry a greater burden today. Achieving the state's goals will require contributions from all Californians and the equitable allocation of benefits and costs must be prioritized. Funding sources for state priorities should be reevaluated as well. For example, funding state-mandated public purpose programs from the state's budget instead of electric and gas bills should promote more equitable recovery of program costs. Additionally, the state should perform an immediate evaluation of all GHG reduction programs and policies to determine which deliver the greatest benefits relative to the cost, and then phase out ineffective programs.

2. **Prioritizing electric sector reliability.** Policymakers, regulators and electricity providers will need to do more long-term planning and develop updated tools to help ensure electric system reliability as the state decarbonizes. This will require a longer planning horizon, early approval of long-lead transmission projects, updated methods for assessing reliability and fair compensation for reliability services.

3. **Enabling deployment of decarbonization infrastructure.** California residents must adopt the use of significant numbers of electric vehicles and appliances to achieve state goals. Importantly, the electric system must be ready to provide clean and reliable electricity for these new uses. By clearing challenges to approving, siting, permitting and interconnecting necessary decarbonization infrastructure, policymakers and regulators can help pave the way for faster development and mobilization.

4. **Incentivizing innovation and adaptability.** Near-term investments in innovation are important to lower future costs and improve future performance of new technologies envisioned by the *Roadmap*, including clean dispatchable electric generation, clean fuels and carbon removal technologies such as direct air capture.

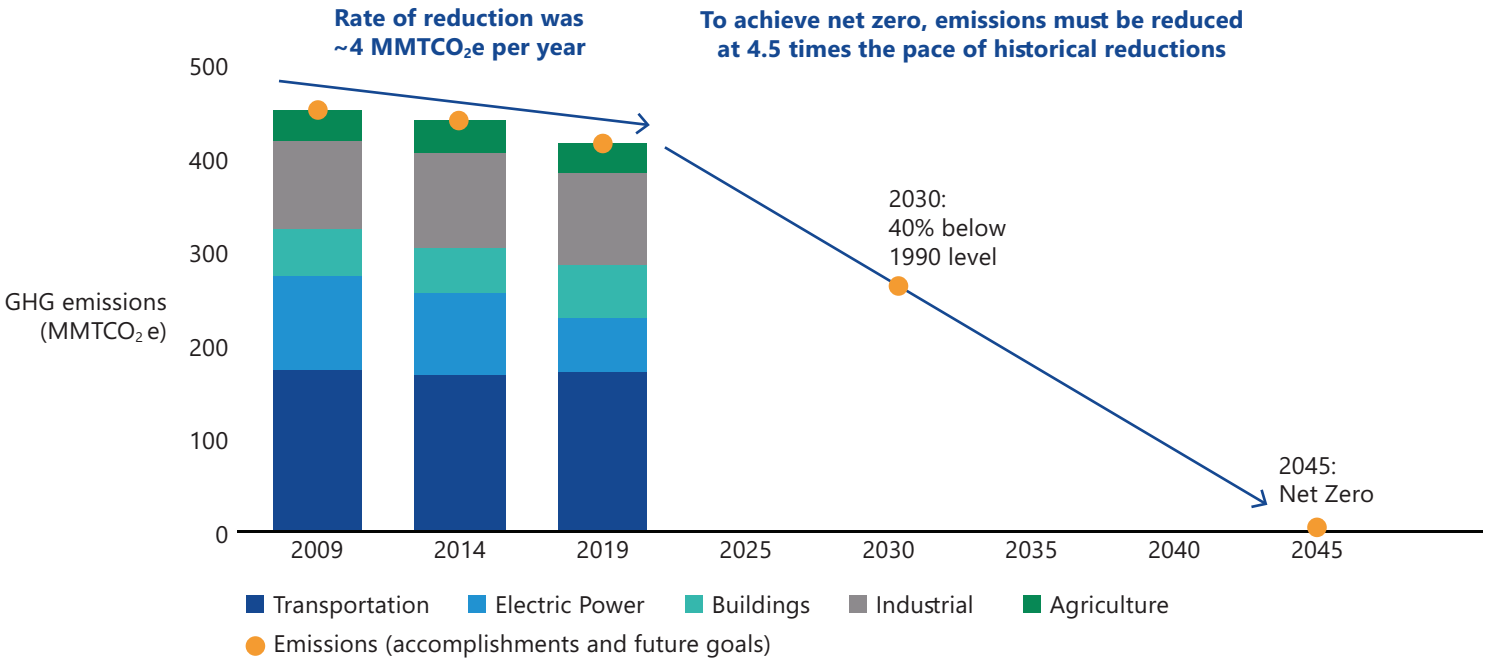
2. Introduction

California has set an ambitious target of achieving carbon neutrality by 2045, with an intermediate requirement to reduce GHG emissions to 40% below 1990 levels by 2030.[4] We believe that the state has the capabilities and experience to not only build the clean energy economy of the future, but also demonstrate an economically and socially sustainable decarbonization model for other states and countries. To do so, it must move much faster than ever before. Although the state reduced GHG emissions by ~36 million metric tons (MMT) from 2009 to 2019 (see Figure 2), it will need to reduce emissions at 4.5 times the pace of historical reductions going forward to reach Net Zero by 2045.

Reliability is the key to enhancing energy resiliency. When the electric system is unreliable, energy users often must turn to ad hoc and costly backup generation (diesel generators, for example) to provide resiliency.[5] The *Roadmap* presents SDG&E's recommendation for California to decarbonize in a reliable, affordable and equitable way.

The *Roadmap* aims to advance current research on California's decarbonization pathways. This is the first publicly available analysis to model California decarbonization through 2045 using the industry standard for evaluating electric system reliability and industry modeling software, yielding new insights about the clean dispatchable generation capacity and technologies required to decarbonize reliably.[6]

FIGURE 2
California's decarbonization accomplishments and future goals



Note: California Air Resources Board (CARB) 2000-2019 GHG Inventory (2021 edition, by economic sector), $MMTCO_2e$: Million metric tons of carbon dioxide equivalent

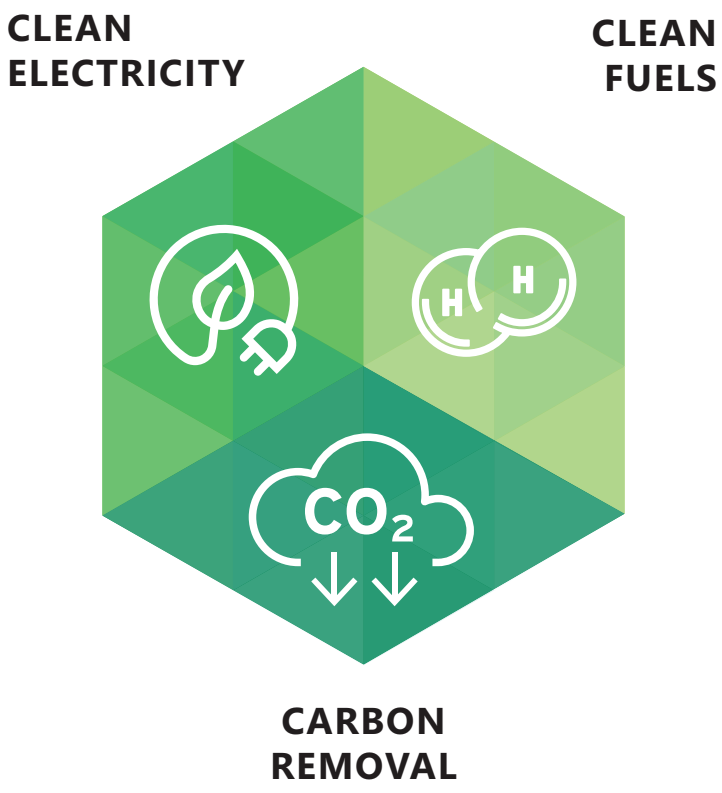
[4] SB 32 ordered a reduction in economywide emissions of 40% below 1990 levels by 2030. Executive Order (EO) B-55-18 established a statewide goal to achieve carbon neutrality by 2045.

[5] See the 2017 National Academies report, Enhancing the Resilience of the Nation's Electricity System, for a longer discussion on reliability and resiliency, available at (https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system).

[6] The analysis applies the North American Electric Reliability Corporation (NERC) "one day in ten year" loss of load expectation (LOLE) standard.

This *Roadmap* employs a diversified approach, with roles for clean electricity, clean fuels and carbon removal technologies, as shown in Figure 3.[7] Rapidly decarbonizing the energy system in a way that ensures reliability, resiliency, affordability and equity will require investments in both existing and emerging decarbonization technologies, including long-term battery storage and clean dispatchable generation, as well as related infrastructure. Given the need for emerging technologies, California must foster innovation and permit adaptability along the journey, adjusting accordingly as the state learns more about people's behavior and decarbonization technologies.

FIGURE 3
Our Roadmap recommends a diversified approach



2.1 *Roadmap* development

Three primary approaches will contribute to economywide decarbonization: (1) the consumption of energy from clean electricity, (2) the consumption of energy from clean fuels and (3) the use of carbon removal technologies.[8] The first two approaches provide end users with decarbonized sources of energy. The third approach directly removes carbon from the atmosphere in situations where clean electricity or clean fuels are cost-prohibitive or technologically infeasible. While reliance on one approach over the other may vary across the different sectors, effective economywide decarbonization will employ a combination of these approaches.

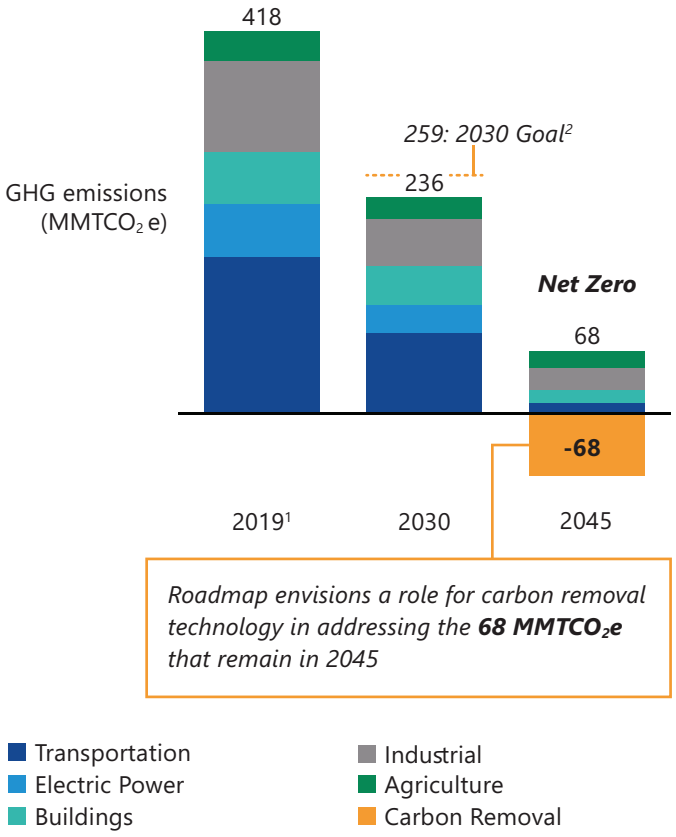
The *Roadmap* was developed by modeling combinations of strategies for decarbonizing each sector of the California economy to achieve the state's goals. As decarbonization strategies were applied, modeling provided insight on the resulting demand for different types of energy, including clean electricity, clean fuels, traditional fossil-fuel based resources and cost. For the electric sector, a cost-optimized electric generation portfolio that both decarbonizes the electric sector and achieves the industry standard of reliability was developed. Finally, while all the combinations of decarbonization strategies evaluated achieved California's 2030 emissions requirement and carbon neutrality by 2045, the study compared the different approaches on reliability, feasibility and affordability to arrive at the *Roadmap* described herein.

[7] While carbon removal technologies are not explicitly modeled in the *Roadmap*, they are the most obvious candidate today to address emissions that will remain in 2045.
[8] "Clean fuels" are low-carbon fuel substitutes (clean hydrogen or renewable natural gas, for example) for traditional fossil fuels. They are distinct from "clean electricity", which provides energy in the form of decarbonized electrical power.

3. Achieving net zero

The diversified approach recommended in the *Roadmap* acknowledges that the exact combination of technologies and investments is unknowable today, and that a diversity of options must be preserved. Figure 4, which illustrates the emissions reduction trajectory across the economy, highlights this point by showcasing the role of carbon removal technologies in addressing 68 MMT of GHG emissions that are not abated with clean electricity or clean fuels.

FIGURE 4
Statewide projected emissions

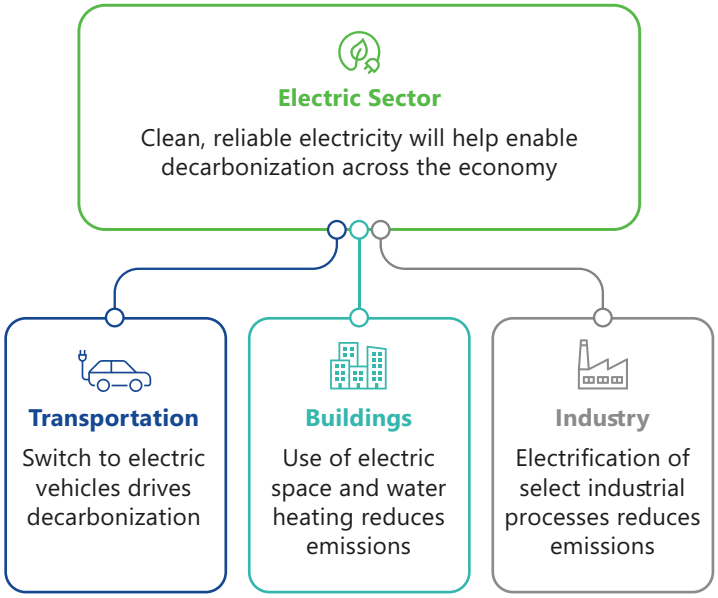


[1] Latest data available from CARB at time of analysis.
[2] Implied cap of emissions to comply with the goal of a 40% reduction, relative to 1990 GHG emissions.

3.1 A clean, reliable electric sector is central to decarbonizing California

California's path to Net Zero hinges on reliably decarbonizing the electric sector, as illustrated in Figure 5.

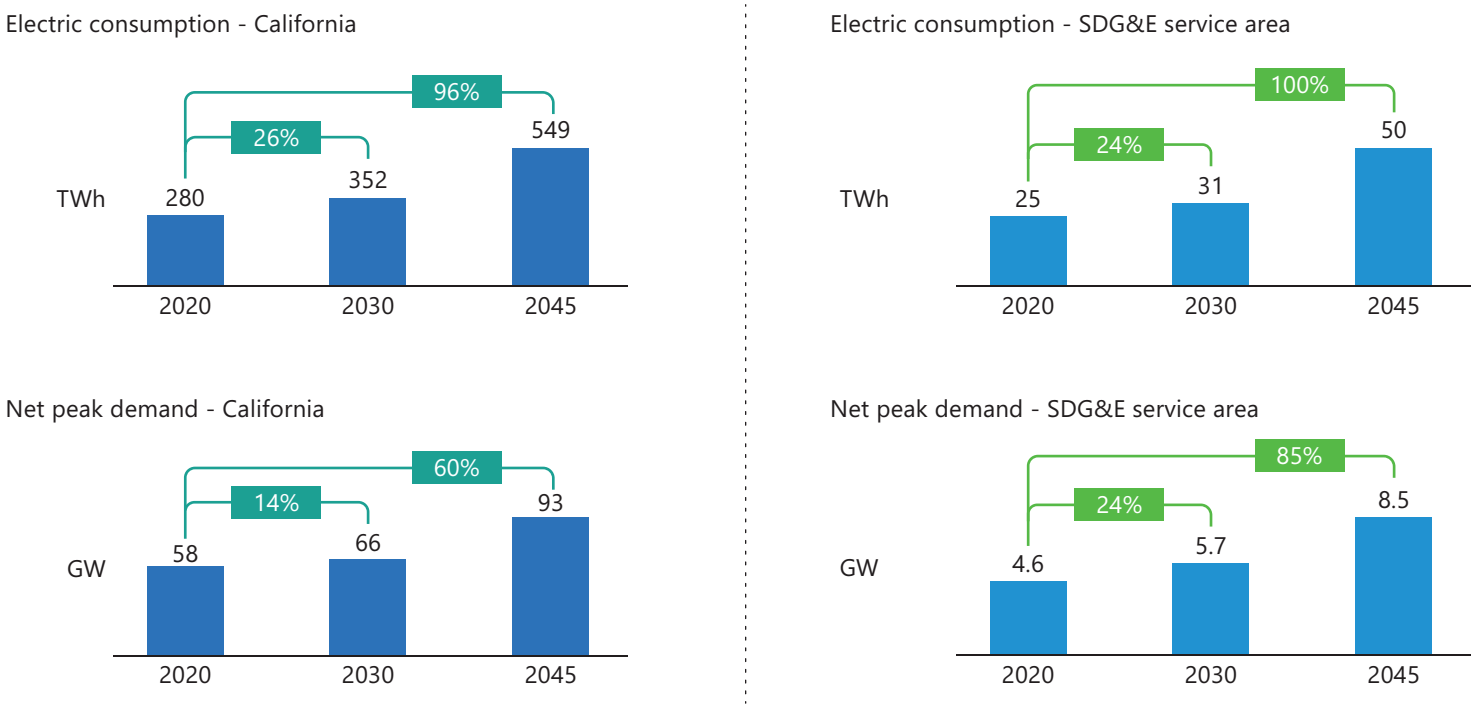
FIGURE 5
The electric sector is expected to be a key enabler to decarbonizing California's economy



The California electric sector is already on a path to reach the goal of 100% of electricity coming from zero-carbon resources by 2045 and has reduced emissions by 42% over the past decade.[9] In 2019, the electric sector accounted for only 14% of California's emissions. As other sectors of the economy electrify, clean and reliable electricity will enable decarbonization more broadly. Figure 6 highlights the transformational growth in electricity demand both in California and the SDG&E service area.

[9] Calculation based on CARB 2000-2019 GHG Inventory (2021 edition, by economic sector).

FIGURE 6
Estimated growth in electric consumption and net peak demand



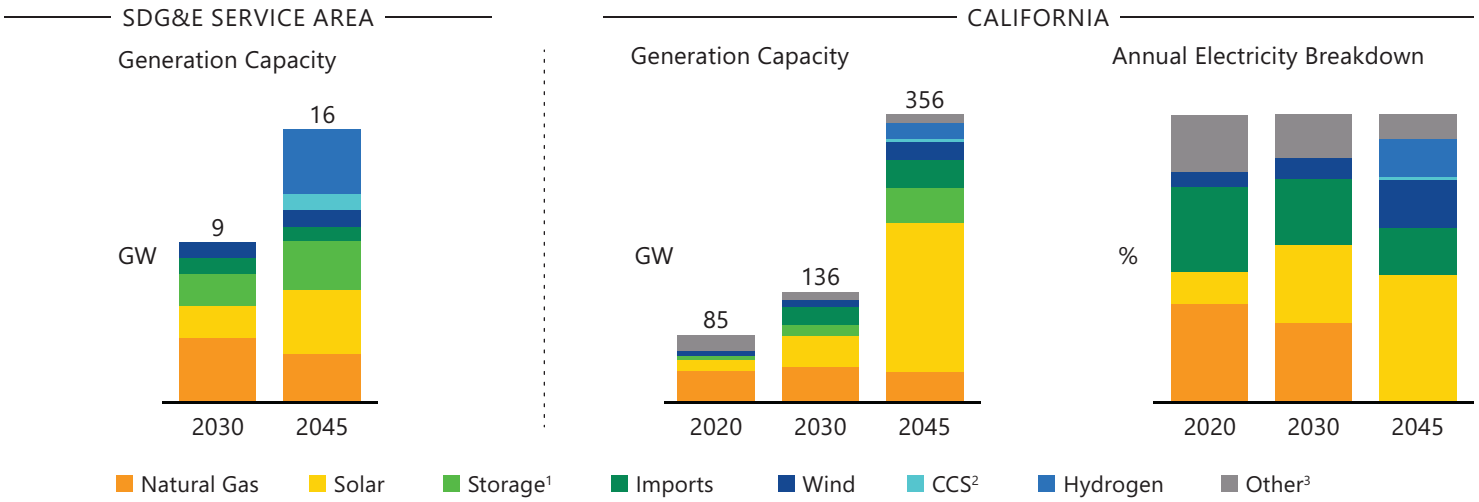
Note: Values represent the difference between base load and behind the meter generation. Values for 2030 and 2045 are based on an average weather year.

To design an electric system capable of reliably meeting the growing demand for electricity, the modeling for the *Roadmap* applied the industry standard for electric reliability – the "one day in ten year" loss of load expectation (LOLE) standard.[10] Notably, ours is the first study to use this industry standard in modeling how the electric sector must support full decarbonization of the California economy through 2045. As most decarbonization pathways depend on a reliable electricity grid, studies that evaluate different decarbonization strategies should also appropriately model electric reliability.

The *Roadmap* envisions deploying a diverse mix of 356 GW of electric generation capacity by 2045. Figure 7 illustrates the envisioned generation capacity mix for California and SDG&E's service area. It projects that 205 GW of in-state solar and wind capacity will comprise 58% of statewide electric generation capacity in 2045, allowing the electric sector to continue to decarbonize while electricity usage increases. The *Roadmap* also recommends the installation of 40 GW of battery storage by 2045.

[10] LOLE is defined as the expected number of days per time period (usually a year) for which the available generation capacity is insufficient to serve the demand at least once per day. LOLE counts the days having loss of load events, regardless of the number of consecutive or nonconsecutive loss of load hours in the day. The study applies the industry standard of 0.1 days per year, or one day in ten years.

FIGURE 7
We believe a diverse set of resources is needed to reliably meet electricity demand



[1] Includes both battery energy storage and pumped hydroelectric storage.
[2] Natural gas generation with CCS. Includes new builds and retrofits.
[3] Other includes oil, coal, geothermal, biomass, hydroelectric and nuclear.

Clean dispatchable electric generators are most critical for keeping the electricity grid reliable while meeting emissions reduction goals. They can both quickly provide electricity to meet customer needs and use a clean fuel source, such as green hydrogen. Resources with these attributes are imperative because they can provide clean energy whenever needed, complementing significant amounts of weather-dependent solar and wind generation.

The intermittency of renewables is one variable that drives the need for clean dispatchable generation. As such, the *Roadmap* envisions 20 GW of 100% clean hydrogen generation as a critical technology needed for the state to maintain electric reliability while satisfying increased demand for clean electricity.[11] To serve this clean dispatchable generation, the *Roadmap* envisions that California will need 6.5 MMT of clean hydrogen in 2045, of which 80% would be for the electric sector.[12] Moreover, in addition to existing natural gas generation, 4 GW of electricity from natural gas with CCS are projected to be needed to support reliability as the electric sector decarbonizes.

As electricity consumption increases, additional electric infrastructure will be necessary for California to support decarbonization. This infrastructure will support reliability and allow California to access 34 GW of imported renewable power by 2045, which should enable the geographic diversification of renewable power and minimize the impact of localized weather events. The *Roadmap* suggests that a larger interconnected western grid is critical to help ensure long-term reliability in California.

The *Roadmap* evaluated several different decarbonization strategies and many of the uncertainties that will affect the future. One area of commonality was the need for California to rapidly expand the construction of wind and solar generators to provide enough clean electricity. Adding these intermittent renewable generation sources requires that the state sustain a diverse generation mix along with many complementary investments that help keep electricity reliable. For instance, every combination of strategies examined also deployed significant amounts of battery storage to support the rapid shift to renewables.

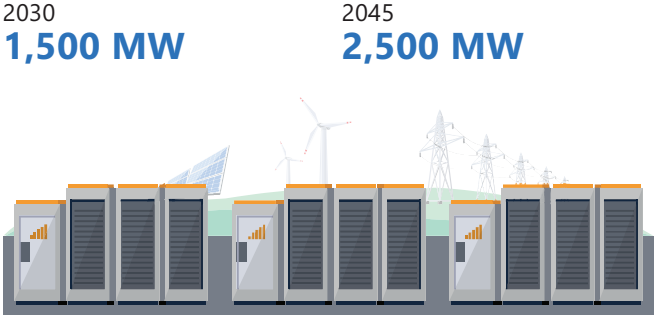
[11] The latest available information was used to inform electric sector modeling and generator characteristics for this analysis, and SDG&E supports a technology-inclusive approach as technology continues to advance for clean dispatchable resources.
[12] The remaining hydrogen is used for hydrogen fuel cell vehicles (HFCV), and for pipeline blending to support decarbonization in the building and industrial sectors.

SPOTLIGHT 1

SDG&E investments in utility-scale battery storage will help ensure reliable power in the SDG&E service area.

At the end of 2020, a combined 331 megawatts (MW) of utility-owned and third-party battery storage were located in SDG&E's service area. To support the reliability of electricity supply, the Roadmap envisions a combined 2,500 MW of utility-owned and third-party battery storage in SDG&E's service area by 2045.

FIGURE 8
Projected battery storage in SDG&E service area



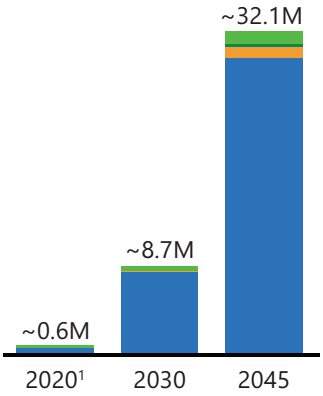
3.2 Transportation electrification is key

As of 2019, the transportation sector, which accounts for approximately 41% of California's emissions, is the state's largest source of GHG emissions.[13] The projected transformational shift to electric vehicles, aligned with state policy and driven by the rapid decline in total cost of owning electric vehicles, will decarbonize a significant portion of the transportation sector.[14] The impact will be considerable for all vehicle types, but particularly so for light-duty cars and trucks (LDV). This shift, however, will create unprecedented demand for electricity. As electrification occurs, it will be critical to learn when Californians charge their vehicles and how they respond to the price of electricity at different times, as their behavior will have a large impact on the electric system. Increasing demands on the electric system can also be managed through advanced vehicle-to-grid integration technologies.[15]

The *Roadmap* anticipates that some portions of the medium-duty vehicle (MDV) and heavy-duty vehicle (HDV) transportation sectors, particularly those requiring long distances and short refueling times, will decarbonize by using clean fuels such as hydrogen.

Figure 9 summarizes the increase in zero-emission vehicles (ZEV) across the state, with a central role for clean electricity and a complementary one for clean fuels.

FIGURE 9
Projected California zero-emission vehicle adoption



	2020[1]	2030	2045
Share, LDV ZEV	2%	27%	87%
Share, MDV + HDV ZEV	-	25%	86%

LDV PHEV + BEV
LDV HFCV
MDV + HDV BEV
MDV + HDV HFCV

[1] 2020 represents actuals based on CEC (2021) Zero-Emission Vehicle and Infrastructure Statistics (for light-duty vehicles only). Note: 2030 + 2045 shown are projected ZEVs (for light-duty, medium-duty, and heavy-duty vehicles).

[13] CARB 2000-2019 GHG Inventory (2021 edition, by economic sector).
[14] EO N-79-20 requires 100% of in-state sales of light-duty vehicles to be zero emission by 2035. BCG, April 21, 2021: *Why Electric Cars Can't Come Fast Enough*, available at https://www.bcg.com/publications/2021/why-evs-need-to-accelerate-their-market-penetration.
[15] Vehicle-to-grid integration technologies were not directly evaluated as part of this study.

SPOTLIGHT 2

SDG&E investments in infrastructure will help enable transportation electrification.

Transportation electrification is estimated to require ~640,000 electric vehicle chargers in SDG&E's service territory by 2045, as shown in Figure 10.[16] SDG&E plans to enable the installation of electric vehicle chargers by deploying the necessary electric infrastructure, which includes utility-side equipment such as transformers. To enhance the equity implications of these investments, SDG&E will continue to work with its customers and partners in diverse, underserved and disadvantaged communities to understand how best to distribute charging infrastructure to meet their transportation needs.

FIGURE 10
Expected EV penetration and charger requirements in SDG&E service area

	2030	2045
Electric vehicles	900K	3,230K
EV chargers	180K	640K

Note: Electric vehicles only. Charger counts represent LD and MD/HD public, workplace and multi-unit dwelling chargers.

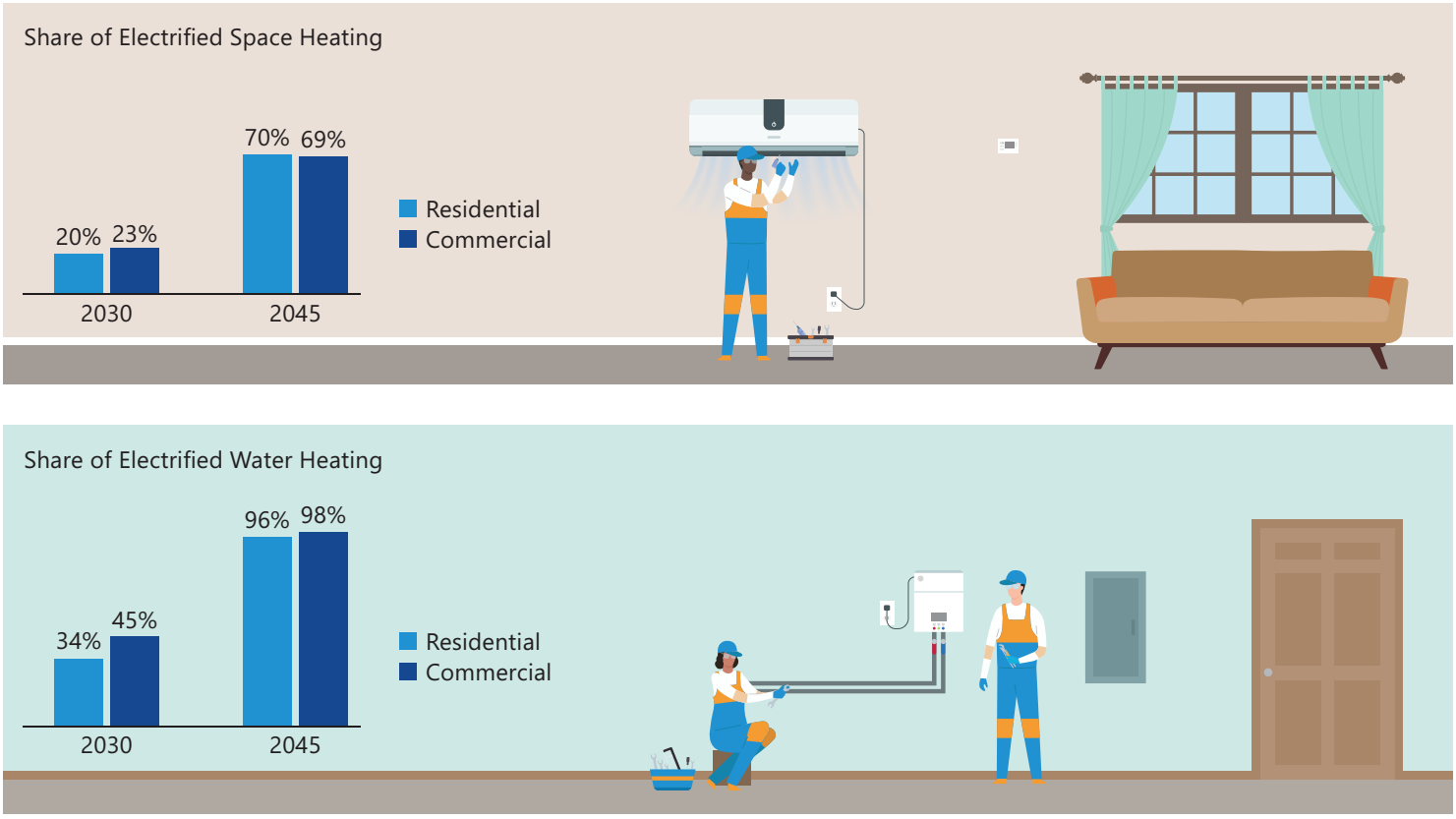
3.3 Clean electricity and clean fuels decarbonize the building sector

The building sector accounts for approximately 14% of California's emissions, primarily from the use of natural gas for space and water heating.[17] These emissions can be decarbonized by electrifying space and water heating equipment or substituting the burning of natural gas with clean fuels. Figure 11 (on the following page) summarizes the penetration of electric space and water heating in residential and commercial buildings needed through 2045 to meet the state's GHG goals.

While the *Roadmap* recommends a substantial role for electrification, it also acknowledges that electrification of appliances can be challenging in certain circumstances. In older homes and some multi-family buildings, substituting a gas appliance with an electric one may require updates to wiring and other electrical infrastructure — an expense and time delay that not all customers can bear. For example, more than half of homes in San Diego County were built in 1979 or earlier, which may require more significant upgrades.[18] This may present an equity concern, as lower-income residents are more likely to live in older homes which may not be able to support electric space and water heating without significant upgrades.[19] Where electrification is not feasible, clean fuels such as renewable natural gas and hydrogen provide a viable approach to decarbonization.[20]

[16] Includes public, workplace and multi-unit dwelling chargers to support light, medium and heavy-duty vehicles.
[17] CARB 2000-2019 GHG Inventory (2021 edition, by economic sector) and 2019 CEC Residential Appliance Saturation Survey (RASS).
[18] Data from the U.S. Census Bureau, 2019 American Community Survey (ACS) 5-Year Estimates Data Profiles, Table DP04, available at https://data.census.gov/cedsci/table?q=housing&g=0100000US_0400000US06_0500000US06073&tid=ACSDP5Y2019.DP04.
[19] Li, Sijei. Where Is the Aging Housing Stock in the United States? Freddie Mac, June 1, 2021, available at https://my.sf.freddiemac.com/updates/news/news~where-is-the-aging-housing-stock-in-the-united-states.
[20] See Rocky Mountain Institute, *The Economics of Electrifying Buildings*, available at https://rmi.org/insight/the-economics-of-electrifying-buildings/.

FIGURE 11
Projected electrification of space and water heating in California and SDG&E service area



SPOTLIGHT 3

SDG&E will explore ways to assist residential customers in electrifying their space and water heating.

Changes in water and space heating appliances can be disruptive and expensive. Contractors and customers may be unfamiliar with electric solutions like heat pump products. One way SDG&E can support the electrification of water and space heating would be to sponsor contractor and consumer education programs to be run by a third-party. Contractors could obtain a "green" certification to market their knowledge of electric solutions. Such programs could be tied to incentives for residential customers to switch appliances, which may improve access to electrification for lower-income households. SDG&E also plans to work with municipal partners, community organizations and community choice aggregators (CCA) on regional policies, funding sources and building reach codes designed to encourage residential electrification. Additionally, SDG&E is developing an innovative rate option to make electrification more attractive to residential customers who may be considering electric heat pumps, among other technologies.

3.4 The industrial sector will require a diverse set of strategies

California is the number one manufacturing state with some of our nation's largest ports.[21] California's industrial sector accounts for 24% of state emissions, stemming from a variety of sources such as manufacturing, petroleum refining and waste management.[22] Decarbonizing this sector will require a combination of approaches.

Electrification is appropriate for a small segment of applications, such as industrial processes involving low-temperature heat. Clean fuels are critical for further reducing emissions from industrial and building uses that cannot be electrified. The *Roadmap* envisions that by 2045 the combination of gaseous fuels flowing through the gas pipeline to homes and businesses will be very different than it is today, as illustrated in Figure 12. While overall throughput in the natural gas pipeline is projected to decrease 65% by 2045, it is projected that almost half of the gas remaining in the pipeline is comprised of hydrogen and renewable natural gas, resulting in lower emissions. This reduces emissions from industrial processes and building appliances that cannot feasibly be electrified.

FIGURE 12
Projected composition of pipeline gas in 2045

[21] BEA manufacturing employment 2020 data by metropolitan area (March 2022).
[22] CARB 2000-2019 GHG Inventory (2021 edition, by economic sector).

4. Decarbonization can be affordable and equitable

The *Roadmap* estimates California will need a relatively small share of state GDP on an annual basis through 2045 to reliably achieve its decarbonization goals.[23] This is based on an assessment of investments needed in electric vehicles, electric appliances and electric infrastructure, as well as the ongoing cost of electricity and fuel, such as gasoline.[24]

The estimated cost of decarbonization is primarily comprised of investments in equipment stock such as the purchase of a new electric vehicle or appliance by consumers. The remainder of the costs include the costs for fuel and electric generation. Decarbonization efforts must be carefully planned to help ensure that California residents, businesses and organizations can afford costs and realize benefits in an equitable manner. Successfully achieving an equitable outcome will be contingent on customer acceptance of clean technologies, innovation and policy incentives.

SDG&E is acutely aware of the financial challenges facing consumers and the above-average inflation trends experienced over the past two decades.[25] Balancing the rising costs of decarbonization with affordability is a challenge that must be addressed.

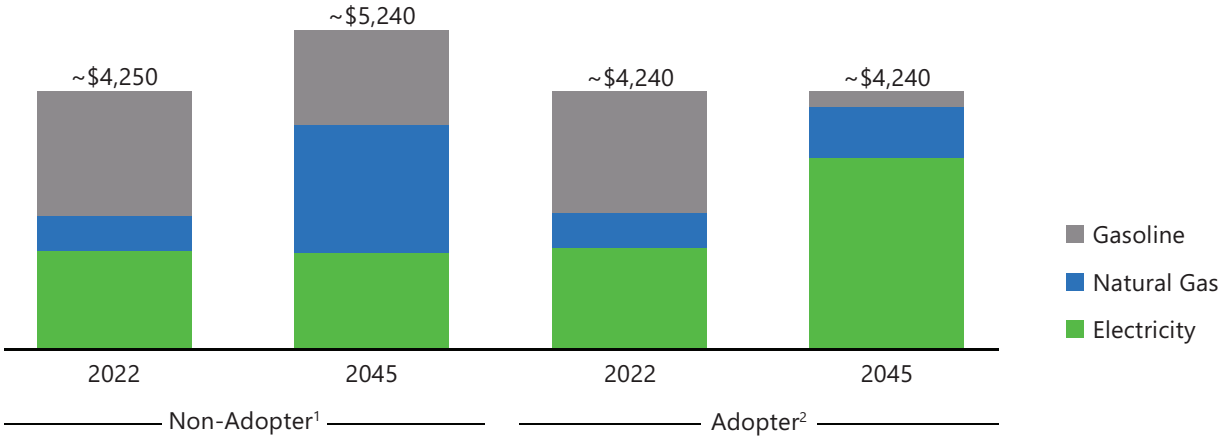
Illustrative changes in SDG&E residential customers' total annual energy expenditures in 2045 were evaluated to better understand future impacts of decarbonization on affordability and equity. This analysis included projected ongoing costs (electric utility bills, gas utility bills and gasoline costs).[26] Two distinct customer types were analyzed – a "Non-Adopter" who makes no changes to their base 2022 electricity and natural gas consumption and owns gasoline vehicles, and an "Adopter" who adopts electric appliances and vehicles at the average rate of the *Roadmap*.

[23] Costs are estimated using methods detailed in the technical appendix. The share of state GDP declines from 8% in 2022 to 6% in 2045. 2021 California GDP was grown by 2.7% annually through 2045 (represents 10-year historical real growth rate), per the U.S. BEA GDP by State SQGDP2.
[24] Investments are in real 2021 dollars. They are not incremental to a business-as-usual case and therefore include costs that are likely to be spent regardless of decarbonization efforts (i.e., purchasing a car or appliance).
[25] 20-year CPI CAGR of 2.6%, 2.5% and 2.2% for San Diego, California and the U.S., respectively. 2001 – 2021 data from U.S. BLS and CA Department of Industrial Relations.
[26] Does not include upfront capital costs of electric vehicles and appliances.

Figure 13 illustrates that a customer can decarbonize according to the *Roadmap* and pay approximately the same annual energy costs in 2045 compared to 2022, excluding the impact of inflation. While the two customer types start at roughly the same household annual energy costs in 2022, an "Adopter" is projected to have 19% lower annual energy costs compared to a "Non-Adopter" by 2045, as shown in Figure 13.[27]

It is important to note that a customer may not be a "Non-Adopter" by choice. Lower-income customers are some of the least likely candidates to be able to adopt electrification technologies due to financial constraints and other obstacles. This highlights the need to help ensure all customers can adopt new technologies to avoid potentially disproportionate financial impacts. To help ensure an affordable and equitable outcome, policymakers, regulators and SDG&E must consider how changes across the economy will affect different households, especially those of average and lower-income customers.

FIGURE 13
Illustrative SDG&E residential customer projected annual household energy spend



[1] Non-Adopters are those customers who make no changes to their base 2022 electricity and natural gas consumption and own gasoline vehicles.
[2] Adopters are those customers who adopt electrified appliances and electric vehicles at the average rate of the Roadmap.
Note: Figures shown represent real 2021 dollars (excludes inflation effects). Analysis is for ongoing costs only (does not include upfront capital costs of electric vehicles and appliances). Please see technical appendix for additional details.

[27] Represents real 2021 dollars. Excludes future inflation effects. Please see technical appendix for additional details.

5. Proactive policy support is essential

The *Roadmap* recommends four types of regulatory and political support to achieve successful implementation: (1) maintain affordability and enhance equity, (2) prioritize electric system reliability, (3) enable deployment of decarbonization infrastructure and (4) incentivize innovation and adaptability.

1. **Maintain affordability and enhance equity.**

    a. **Reform electric and gas pricing, as well as explore alternative funding and cost recovery mechanisms.** Historically, electric rates in California have been designed to promote conservation by collecting nearly all costs through volumetric rates. As a result, electricity rates in California are some of the highest in the country, creating a disincentive for additional electrification. As the energy landscape and customer usage patterns evolve, so should electric rate design. Changing how electricity is priced to encourage the electrification of vehicles and appliances, while promoting bill stability, will be key to managing the costs of decarbonization. To help ensure an equitable outcome for all customers, electric rate design that creates subsidies from one group of utility customers to another in an effort to incentivize specific decarbonization technologies should be avoided.

    Regarding natural gas customers, a similar overhaul of gas rates should be considered. As residential and commercial buildings increasingly electrify, natural gas throughput is projected to decline. Therefore, customers that continue to use gas will pay a disproportionate share to maintain a safe and reliable gas grid. Changes to gas rate design can mitigate these impacts and help ensure fairness across different types of customers.

    Moreover, the cost of decarbonizing California should be shared equitably. Alternative funding and recovery mechanisms will need to be explored to help reduce the costs borne by utility customers. For example, California's energy policy framework should be set up to maximize its ability to leverage federal funding, including in the recently passed Infrastructure Investment and Jobs Act, and more generally from the Department of Energy. State funding mechanisms should be reevaluated as well. For example, transitioning costs associated with state-mandated public purpose programs from electric and gas bills to the state's budget should promote more equitable cost recovery and reduce unnecessary pressure on household electricity and gas costs.

    b. **Support low-income households so they can benefit from the clean energy transition.** To avoid disproportionately burdening low-income households, policymakers and regulators should learn how changes in energy usage across the economy will affect financially fragile households. Policy and regulatory support, such as appropriately designed incentive programs to assist consumers with the upfront costs of new electric appliances and vehicles, will help ensure lower-income households benefit from California's decarbonization efforts. The impact of decarbonization on social equity will depend on how strategies to achieve Net Zero are implemented.

    c. **Evaluate and prioritize cost-effective emission reductions programs.** California has enacted dozens of programs and policies to reduce GHG emissions. As we focus on the future, affordability is a key consideration

of customer acceptance and support of decarbonization. The state should continue to pursue cost effective energy efficiency and demand response programs, while also performing an immediate evaluation of all GHG reduction programs and policies to determine which deliver the greatest benefits relative to the cost. Following this review, the Legislature, California Public Utilities Commission (CPUC) and California Energy Commission (CEC) should take steps to sunset costly and ineffective programs to maximize limited ratepayer funds. The state should repeat this process on a regular basis.

d. **Support an equitable transition for affected workforces.** California's energy ecosystem employs highly skilled professionals, such as boilermakers, pipefitters, welders, and laborers whose jobs may be at risk from electrification. However, these skills will still be necessary in a decarbonized future. Policymakers and regulatory agencies should prioritize helping such workers evolve their skills on the journey to carbon neutrality.

2. **Prioritize electric system reliability.**

a. **Incorporate electric sector reliability into long-term state planning.** State agencies and load serving entities that are evaluating future electric generation should apply the industry reliability standard when assessing decarbonization options through 2045. A reliable energy system is essential for California, its residents and its economy. Achieving electric reliability will require fairly compensating providers of reliability services, developing new methods for assessing reliability in light of future uncertainties and reforming transmission planning processes. This includes using electricity demand forecasts aligned with state goals in planning processes and timely approval of long-lead transmission projects to accommodate increasing electrification.[28]

b. **Implement a regional transmission organization (RTO).** Recognizing that California is part of an electric system that extends beyond its borders, SDG&E continues to be supportive of the California Independent System Operator (CAISO) RTO market expansion efforts and broader long-term western regionalization based upon the belief that it will lead to market efficiency, optimization of renewable resources across the West and enhanced grid reliability.

c. **Adopt technology inclusive solutions.** Adopting a technology inclusive definition of clean energy should enhance reliability and affordability. Current policies, such as the Joint Agencies interpretation of SB 100, exclude certain technologies because they produce some emissions, even though they could support reliable decarbonization of the electric sector.[29] Technologies such as blending hydrogen into the fuel mix for natural gas generators or natural gas generation with CCS can enable California to meet its interim emissions goals and help ensure reliability. Policymakers and regulators should adopt a fuel-agnostic definition of clean energy that includes a diverse set of technologies.

3. **Enable deployment of decarbonization infrastructure.** As a growing number of California residents adopt electric vehicles and electric space and water heaters, the electric system must be ready to provide increasing amounts of clean and reliable electricity. Obstacles to approving, siting, permitting and interconnecting decarbonization technologies can prevent or slow the pace of decarbonization. Federal, state and local policymakers can:

[28] Electricity forecasts representative of state goals could be incorporated into the CPUC Integrated Resource Plan, CAISO's Transmission Planning Process and the CEC's Integrated Energy Policy Report (IEPR).
[29] The Joint Agencies include the CEC, CPUC and CARB.

a. Enable faster infrastructure development by updating planning efforts for clean electricity and fuels.

b. Simplify and accelerate regulatory reviews.

c. Authorize land use for decarbonization technologies.

d. Increase access to federal- and state-controlled rights-of-way.

e. Simplify the processes to use or cross federal lands.

f. Develop planning processes for new types of infrastructure, such as the production and distribution of clean hydrogen.

These actions will be critical to interconnect new electric generation capacity and to mobilize investments in transmission and distribution within California and across the Western U.S.

4. **Incentivize innovation and adaptability.** The state should encourage research, development and demonstration efforts to make sure necessary decarbonization technologies are available for deployment at an affordable cost. This will require incentivizing pilots, demonstration projects and large-scale deployments to meet an increasingly rapid pace of decarbonization. It also will require facilitating engagement with private and public sector partners across the U.S. and globally on decarbonization research and development.

   Since these initiatives may reveal more impactful or cost-effective approaches to decarbonization, the state should also foster an environment of experimentation, learning and adaptability on the way to carbon neutrality. Adopting a diversified approach will preserve optionality. The state should also continuously take a forward-looking view and be willing to permit investments for learning opportunities by creating supportive policy frameworks for promising technologies, such as CCS. Finally, an important component of adaptability involves recognizing when policies are not working as intended, are not cost effective or generally are no longer serving the public interest.

6. SDG&E is ready to partner

Achieving the objectives outlined in the *Roadmap* cannot be accomplished by SDG&E alone, as we are one player within a larger region. It will require time, investment and coordination from all stakeholders who share the goal of achieving carbon neutrality while maintaining a reliable electric system. To that end, SDG&E looks forward to sharing our findings with local and state agencies, community-based organizations, CCAs, other utilities and the public to explore opportunities with those who share our mission.

Economywide decarbonization will only be possible through the combined efforts of all stakeholders in the state. SDG&E is committed to doing its part and has established a sustainability target where we aim to have Net Zero emissions by 2045. SDG&E will continue to invest in decarbonization efforts to reduce the carbon content of energy used in key segments of the economy, including the transportation, electric and building sectors. These initiatives are described in SDG&E's sustainability reports published in 2020 and 2021.[30]

These reports demonstrate a partial list of what SDG&E has already accomplished:

Climate adaptation and wildfire safety
Over the past decade, SDG&E has invested more than $3 billion in establishing an industry-leading wildfire safety and climate adaptation program, which includes undergrounding power lines, strengthening regional emergency preparedness and improving situational awareness through advanced technologies such as live-streaming, fire-monitoring cameras and artificial intelligence (AI)-based fire forecast models. In the past 14 years, SDG&E equipment has not been the cause of any major wildfires, which are a major source of carbon and air pollution in California.

Reliability
For the last 16 consecutive years, SDG&E has been the most reliable electric utility in the West and in 2021, we were named by PA Consulting as the most reliable electric utility in the nation for the second time.[31]

[30] See *Building a Better Future: Our Commitment to Sustainability*, SDG&E, October 2020; *Building a Better Future: Sustainability Strategy Update*, SDG&E, October 2021, both available at https://www.sdge.com/more-information/environment/sustainability-approach.
[31] See *SDG&E Wins National Award For Best Electricity Reliability in America, Outstanding Reliability in the West & Grid Sustainability*, available at https://www.sdgenews.com/article/sdge-wins-national-award-best-electric-reliability-america-outstanding-reliability-west, November 2021.

Clean transportation
SDG&E has built more than 3,200 electric vehicle chargers and expects to build thousands more in the coming years to support not just passenger vehicles, but also medium- and heavy-duty vehicles, such as trucks and buses. SDG&E is also working to transition its fleet to 100% zero-emissions vehicles by 2035. In 2020, SDG&E, in partnership with regional stakeholders, established the Accelerate to Zero (A2Z) Emissions Collaboration to support transportation electrification in San Diego.

Battery storage
Over the past decade, SDG&E has built a diverse energy storage portfolio and is rapidly scaling up both its owned and contracted storage capacity. SDG&E is on track to double its owned storage capacity to 145 MW by the end of 2022. Additionally, we have another 284 MW of energy storage under contract.

Microgrids
SDG&E is pioneering zero-emission microgrids, like the Ramona Air Attack Base, as backup power to support vulnerable populations and critical facilities during emergencies. Since building America's first utility-scale microgrid in 2013, SDG&E has been working to add more throughout our service area. Currently, we have about a dozen microgrids that are either complete or under development.

Methane emissions reduction
2021 marks the fifth consecutive year SDG&E has achieved a zero leak repair backlog, supporting efforts to reduce methane emissions. Also contributing to the reduction of methane emissions are the SDG&E's 24-hour gas emergency response crews whose average response time to gas emergencies is under 30 minutes, enabling much quicker control of escaping gas.

Operational innovations
As part of a large-scale project to upgrade a natural gas transmission pipeline, SDG&E is deploying cutting-edge fiber optic sensing technology to monitor and locate digging vibrations near the pipe to protect against dig-ins and leaks. Enhanced analytics from fiber optics will help operators respond more quickly to issues and prevent natural gas from escaping into the atmosphere. Additionally, SDG&E is recapturing gas that needs to be purged from a pipeline during construction and re-injecting it back into the system for customer use.

Urban greening
Since launching its sustainability strategy in October 2020, SDG&E has planted more than 10,000 trees, leveraging a nature-based solution to capture carbon and clean the air.

To help ensure that decarbonization is equitable, SDG&E will continue investing in its "Outside In" community outreach program to meet the needs of diverse, underserved and disadvantaged communities through sustainability initiatives.

Acronyms & abbreviations

AI: Artificial Intelligence

BEV: Battery Electric Vehicle

CAISO: California Independent System Operator

CARB: California Air Resources Board

CCS: Carbon Capture and Sequestration

CEC: California Energy Commission

CPUC: California Public Utilities Commission

EO: Executive Order (in this instance, referring to an order issued by the Governor of California)

EV: Electric Vehicle

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GW: Gigawatts

HDV: Heavy-Duty Vehicle

HFCV: Hydrogen Fuel Cell Vehicle

LDV: Light-Duty Vehicle

LOLE: Loss of Load Expectation

MDV: Medium-Duty Vehicle

MMT: Million Metric Tons

MW: Megawatts

NERC: North American Electric Reliability Corporation

PHEV: Plug-in Hybrid Electric Vehicle

RTO: Regional Transmission Organization

SB: Senate Bill (in this instance, referring to a bill passed by the California Senate)

TWh: Terawatt Hours

ZEV: Zero-Emission Vehicle

Glossary

Carbon Capture & Sequestration (CCS): The process of capturing carbon dioxide (CO_2) from a stationary source of emissions, typically an industrial facility or power plant. The CO_2 is then compressed, transported and permanently sequestered.

Carbon Neutrality: All greenhouse gas (GHG) emissions emitted into the atmosphere are balanced in equal measure by GHGs that are removed from the atmosphere. In this report, this is used interchangeably with Net Zero Emissions.

Carbon Removal Technologies: A term that encompasses many forms of GHG removal from the atmosphere, whether through carbon sequestration in natural and working lands, or through negative emissions technologies that actively pull carbon dioxide out of the atmosphere, such as direct air capture or biomass energy with CCS.

Clean Fuels: Low-carbon fuel substitutes, like clean hydrogen produced with renewable energy sources, or renewable natural gas, for fossil fuels such as natural gas. They are distinct from "clean electricity," which provides energy in the form of decarbonized electrical power.

Clean Hydrogen Generation: Dispatchable electric generators that produce clean electricity by combusting clean hydrogen fuel, typically in a combined cycle turbine.

Decarbonization: The reduction or elimination of CO_2 and other greenhouse gases.

Dispatchable Generation: Electric generation that can be controlled and is available when needed, in contrast to weather-dependent wind and solar generation.

Economywide: Including all economic sectors of the California economy (electric, transportation, residential, commercial, industrial and agriculture).

Electric Generation Capacity: The maximum output an electric power generator can produce; for large facilities, like at the scale generally contracted or owned by utilities, this is measured in megawatts (MW) or gigawatts (GW).

Electric Reliability: The degree to which the electric power system can deliver electricity to consumers in the amount desired, and within the accepted standards.

Electrification: The process of replacing technologies that use fossil fuels with technologies that use electricity as a source of energy.

Energy Transition: The energy sector's shift from fossil-based systems of energy production and consumption to renewable energy.

EO B-55-18: Establishes a statewide goal to achieve carbon neutrality by 2045.

EO N-79-20: Requires 100% of in-state sales of new passenger cars/trucks will be zero emissions by 2035. Requires 100% of in-state sales of medium/heavy-duty vehicles will be zero emissions by 2045. Requires 100% of off-road vehicles/equipment will be zero emissions by 2035.

EO S-3-05: Establishes the following GHG emission reduction targets:

By 2020, Reduce GHG Emissions to 1990 levels;

By 2050, Reduce GHG Emissions to 80% below 1990 levels.

Equity: Offers fair treatment, access, opportunity and advancement for everyone. Equitable practices identify and seek to eliminate barriers that prevent someone's full participation, recognizing that each person's needs are not the same. Climate equity means providing all customers equitable access to clean energy as well as climate resilience tools and technologies.

Gigawatts (GW): A unit of electric power equal to 1,000 megawatts (MW).

Greenhouse Gases (GHG): Gases that trap heat in the atmosphere. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases.

Heavy-Duty Vehicle (HDV): Any motor vehicle with a gross vehicle weight above 26,000 pounds.

Imported Generation: Generation capacity that is physically located outside of California (e.g., Arizona, Nevada), but is connected to the California electric system.

Interconnect: A multistep process that enables an electric generator to interconnect to the electric grid and supply power.

Intermittent (Variable) Generation: Wind and solar generation that is not continuously available due to external factors that cannot be controlled (i.e. weather).

Light-Duty Vehicle (LDV): Any motor vehicle with a gross vehicle weight of 10,000 pounds or less.

Load Serving Entity: Any company that sells or provides electricity to customers located in California.

Long-Term Battery Storage: Battery storage with a duration of 12+ hours.

Loss of Load Expectation (LOLE): A measure of electric reliability. The expected number of days per time period (usually a year) for which the available generation capacity is insufficient to serve electric demand at least once per day.

LOLE counts the days having loss of load events, based on a stochastic variation of historical supply data, regardless of the number of consecutive or nonconsecutive loss of load hours in the day. The study applies the industry standard of 0.1 days per year or 1 day in 10 years.

Make Ready Infrastructure: Electrical infrastructure required to install and operate charging stations, which usually includes utility pad-mounted transformers, underground conduit and meters.

Medium-Duty Vehicle (MDV): Any motor vehicle with a gross vehicle weight between 10,001 and 26,000 pounds.

MMTCO$_2$e: Million Metric Tons of Carbon Dioxide Equivalents. The climate impact of all GHG converted into a mass of carbon dioxide equivalent.

Net Peak Demand: The difference between base electric demand and generation from behind the meter resources.

Net Zero Emissions: All GHG emissions emitted into the atmosphere are balanced in equal measure by GHGs that are removed from the atmosphere. In this report, this is used interchangeably with Carbon Neutrality.

Pipeline Blending: Replacing natural gas with clean fuels, such as renewable natural gas and clean hydrogen, to reduce GHG emissions from using gaseous pipeline fuels.

Renewable Natural Gas: Gas derived from food waste, landfills, agriculture and other sources that release carbon emissions into the atmosphere.

Resiliency: The ability to withstand and reduce the magnitude of disruptive events, which includes the capability to anticipate, adapt to and/or rapidly recover from such an event.

SB 32: Requires that statewide GHG emissions are reduced to 40% below the 1990 level by 2030.

SB 100: Requires that 100% of retail sales of electricity in California be served by eligible renewable energy resources and zero-carbon resources by 2045.

State Mandated Public Purpose Programs: State-mandated programs funded through energy bills like financial assistance for income qualified customers and energy efficiency programs.

Transmission & Distribution: Transmission lines carry electricity at high voltages across the state. Distribution lines deliver lower voltage electricity to neighborhoods and communities over a shorter distance, and are the final stage of electricity delivery to homes and businesses.

Vehicle to Grid Integration: Any method that changes how grid-connected electric vehicles charge or discharge their batteries. This is done to optimize plug-in electric vehicle interaction with the electrical grid and provide net benefits to ratepayers.

Zero-Emission Vehicles (ZEV): Vehicles which produce no emissions from the on-board source of power (i.e., an electric vehicle or fuel cell vehicle).

Disclaimer

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P.O. Box 129831 | San Diego, CA 92112-9831 |
1-800-411-7343 | Connect at sdge.com